the contributions to vehicle emissions in the Las Vegas air basin, where all truck shipments (an average of five per day) would travel under the mostly legal-weight truck scenario, would be small in comparison to those from other vehicle traffic in the area. The annual average daily traffic on I-15 0.3 kilometer (0.2 mile) north of the Sahara Avenue interchange is almost 200,000 vehicles (DIRS 103405-NDOT 1997, p. 7), about 20 percent of which are trucks (DIRS 104727-Cerocke 1998, all). For these reasons, national transportation of spent nuclear fuel and high-level radioactive waste by truck and rail would not constitute a meaningful source of air pollution along the nation's highways and railroads.

J.1.3.2.4 *Sensitivity of Dose Rate to Characteristics of Spent Nuclear Fuel*

For this analysis, DOE assumed that the dose rate external to all shipments of spent nuclear fuel and high-level radioactive waste would be the maximum value allowed by regulations (49 CFR 173.441). However, the dose rate for actual shipments would not be the maximum value of 10 millirem per hour at 2 meters (6.6 feet) from the sides of vehicles. Administrative margins of safety that are established to compensate for limits of accuracy in instruments and methods used to measure dose rates at the time shipments are made would result in lower dose rates. In addition, the characteristics of spent nuclear fuel and high-level radioactive waste that would be loaded into casks would always be within the limit values allowed by the cask's design and its Nuclear Regulatory Commission certificate of compliance.

For example, DOE used data provided in the *GA-4 Legal-Weight Truck Cask Design Report* (DIRS 101831-General Atomics 1993, pp. 5.5-18 and 5.5-19) to estimate dose rates 2 meters (6.6 feet) from transport vehicles for various characteristics of spent nuclear fuel payloads. Figure J-7 shows ranges of burnup and cooling times for spent nuclear fuel payloads for the GA-4 cask. The figure indicates the characteristics of a typical pressurized-water reactor spent nuclear fuel assembly (see Appendix A). Based on the design data for the GA-4 cask, a shipment of typical pressurized-water reactor spent nuclear fuel would result in a dose rate of about 6 millirem per hour at 2 meters from the side of the transport vehicle, or about 60 percent of the limit established by U.S. Department of Transportation regulations (49 CFR 173.441). Therefore, DOE estimates that, on average, dose rates at locations 2 meters (6.6 feet) from the sides of transport vehicles would be about 50 to 70 percent of the regulatory limits. As a result, DOE expects radiological risks to workers and the public from incident-free transportation to be no more than 50 to 70 percent of the values presented in this EIS.

J.1.4 METHODS AND APPROACH TO ANALYSIS OF ACCIDENT SCENARIOS

J.1.4.1 Accidents in Loading Operations

J.1.4.1.1 *Radiological Impacts of Loading Accidents*

The analysis used information in existing reports to consider the potential for radiological impacts from accidents during spent nuclear fuel loading operations at the commercial and DOE sites. These included a report that evaluated health and safety impacts of multipurpose canister systems (DIRS 104794-CRWMS M&O 1994, all) and two safety analysis reports for onsite dry storage of commercial spent nuclear fuel at independent spent fuel storage installations (DIRS 103449-PGE 1996, all; DIRS 103177-CP&L 1989, all). The latter reports address the handling and loading of spent nuclear fuel assemblies in large casks similar to large transportation casks. In addition, DOE environmental impact statements on the management of spent nuclear fuel and high-level radioactive waste (DIRS 101802-DOE 1995, all; DIRS 101816-DOE 1997, all) provided information on radiological impacts from loading accidents.

DIRS 104794-CRWMS M&O (1994, Sections 3.2 and 4.2) discusses potential accident scenario impacts of four cask management systems at electric utility and other spent nuclear fuel storage sites. This report concentrated on unplanned contact (bumping) during lift-handling of casks, canisters, or fuel assemblies. The two safety analysis reports for independent spent fuel storage installations for commercial spent

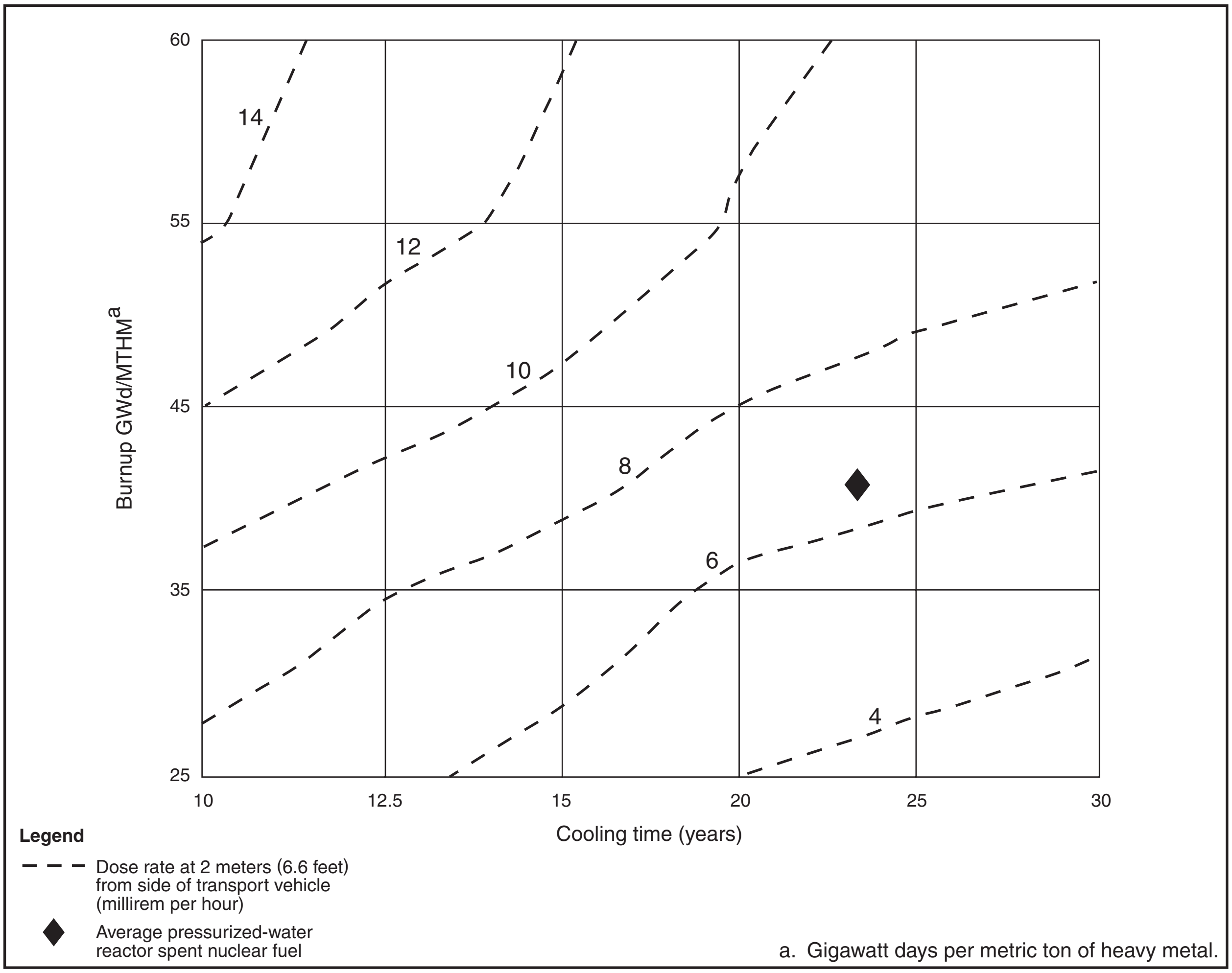

Figure J-7. Comparison of GA-4 cask dose rate and spent nuclear fuel burnup and cooling time.

nuclear fuel (DIRS 103449-PGE 1996, all; DIRS 103177-CP&L 1989, all) evaluated a comprehensive spectrum of accident-initiating events. These events included fires, chemical explosions, seismic events, nuclear criticality, tornado strikes and tornado-generated missile impacts, lightning strikes, volcanism, canister and basket drop, loaded shipping cask drop, and interference (bumping, binding) between the transfer cask and storage module. The DOE environmental impact statements for the interim management of spent nuclear fuel and high-level radioactive waste (DIRS 101802-DOE 1995, Volume 1, Appendix E; DIRS 101816-DOE 1997, Appendixes F and G) included radiological impacts from potential accident scenarios associated with preparing, storing, and shipping these materials. These EISs do not discuss quantitative radiological impacts for accident scenarios associated with material loading, but do contain estimates of radiological impacts from accident scenarios for the spent nuclear fuel and high-level radioactive waste management activities considered. As discussed for routine loading operations, this analysis converted radiation doses to estimates of radiological impacts using dose-to-risk conversion factors of the International Commission on Radiological Protection.

The DIRS 104794-CRWMS M&O (1994, all) study concluded that radiological impacts from handling incidents would be small. The population dose (person-rem) for accidents in handling the four cask systems considered in the study would vary from 0.1 rem to 0.04 rem. This dose would be the total for all persons who would be exposed, onsite workers as well as the public. The highest estimated dose (0.1 person-rem) could result in 0.00005 latent cancer fatality in the exposed population.

J.1.4.1.2 *Industrial Safety Impacts of Loading Operations at Commercial Facilities*

The principal industrial safety impact parameters of importance to commercial industry and the Federal Government are (1) total recordable (injury and illness) cases, (2) lost workday cases associated with workplace injuries and illnesses, and (3) workplace fatalities. The frequency of these impacts under the Proposed Action and the inventory modules (Modules 1 and 2) was projected using the involved worker level of effort, expressed as the number of full-time equivalent worker multiples, that would be needed to conduct shipment tasks. The workplace loss incidence rate for each impact parameter [as shown in a Bureau of Labor Statistics summary (DIRS 148091-BLS 1998, all)] was used as a multiplier to convert the level of effort to expected industrial safety losses.

DOE did not explicitly analyze impacts to noninvolved workers in its earlier reports (DIRS 101747-Schneider et al. 1987, all; DIRS 104791-DOE 1992, all). However, for purposes of analysis in this EIS, DOE estimated that impacts to noninvolved workers would be 25 percent of the impacts to the involved workforce. This assumption is based on (1) the DOE estimate that about one of five workers assigned to a specific task would perform administrative or managerial duties, and (2) the fact that noninvolved worker loss incidence rates are generally less than those for involved workers (see Appendix F, Section F.2.2.2).

The estimated involved worker full-time equivalent multiples for each shipment scenario were estimated using the following formula:

$$\text{Involved worker full-time equivalent multiples} = (A \times B \times C \times D) \div E$$

where: A = number of shipments (from Tables J-5 and J-6)

B = average loading duration for each shipment by fuel type and conveyance mode (workdays; from Table J-13)

C = workday conversion factor = 8 hours per workday

D = involved worker crew size (13 workers; from Table J-14)

E = full-time equivalent conversion factor = 2,000 worker hours per full-time equivalent

The representative Bureau of Labor Statistics loss incidence rate for each total recordable case, lost workday case, and fatality trauma category (for example, the number of total recordable cases per full-time equivalent) was then multiplied by the involved worker full-time equivalent multiples to project the associated incidence. The involved worker total recordable case incidence rate used was that reported for the Trucking and Warehousing sector for 1998 because neither the Nuclear Regulatory Commission nor the Bureau of Labor Statistics maintains data on commercial power reactor industrial safety losses. The total recordable case incidence rate, 145,700 cases in a workforce of 1.74 million workers (8.4 total recordable cases per 100 full-time equivalents), is the averaged loss experience for 1998. The Trucking and Warehousing sector was chosen because DOE assumed the industrial operations and hazards associated with activities in this sector would be representative of those encountered in handling spent nuclear fuel casks at commercial power reactor sites and DOE facilities. Because lost workday cases are linked to the total recordable case experience (that is, each lost workday case would have to be included in the total recordable case category), the same period of record and facilities was used in the selection of the involved worker lost workday case incidence rate [80,800 lost workday cases in a workforce of 1.74 million workers (4.6 lost workday cases per 100 full-time equivalents)].

The involved worker fatality incidence rate reported by the Bureau of Labor Statistics (1.8 fatalities among 100,000 workers) for the Trucking and Warehousing sector during the DIRS 148091-BLS (1998, all) period of record was used.

DOE used the same Bureau of Labor Statistics data sources to estimate total recordable case, lost workday case, and fatality incidence rates for noninvolved workers.

J.1.4.1.3 *Industrial Safety Impacts of DOE Loading Operations*

The technical approach and loss multipliers discussed in Section J.1.4.1.2 for commercial power reactor sites analysis were used for the analysis of spent nuclear fuel and high-level radioactive waste loading impacts at DOE sites. Because no information existed on the high-level radioactive waste loading duration for the truck and rail transportation modes, DOE assumed that the number of full-time equivalent involved workers for the two transportation modes would be the same as that for the DOE sites shipping spent nuclear fuel. For those sites, the average number of full-time equivalent workers would be about 0.07 and 0.12 per shipment for the truck and rail transportation modes, respectively.

J.1.4.2 Transportation Accident Scenarios

J.1.4.2.1 *Radiological Impacts of Transportation Accidents*

Potential consequences and risks of transportation would result from three possible types of accidents: (1) accidents in which there is no effect on the cargo and the safe containment by transportation packages is maintained, (2) accidents in which there is no breach of containment, but there is loss of shielding because of lead shield displacement, and (3) accidents that release and disperse radioactive material from safe containment in transportation packages. Such accidents, if they occurred, would lead to impacts to human health and the environment. The following sections describe the methods for analyzing the risks and consequences of accidents that could occur in the course of transporting spent nuclear fuel and high-level radioactive waste to a nuclear waste repository at the Yucca Mountain site. They discuss the bases for, and methods for, determining rates at which accidents are assumed to occur, the severity of these accidents, and the amounts of materials that could be released. Accident rates, severities, and the corresponding quantities of radioactive materials that could be released are essential data used in the analyses. Appendix A presents the quantities of radioactive materials in a typical pressurized-water reactor spent nuclear fuel assembly used in the analysis of accident consequences and risks. Legal-weight truck casks would usually contain four pressurized-water reactor spent nuclear fuel assemblies, and rail casks would usually contain 24 (see Table J-3).

In addition to accident rates and severities, an important variable in assessing impacts from transportation accident scenarios is the type of material that would be shipped. Accordingly, this appendix presents information used in the analyses of impacts of accidents that could occur in the course of transporting commercial pressurized- and boiling-water reactor fuels, DOE spent nuclear fuels, and DOE high-level radioactive waste.

For exposures to ionizing radiation and radioactive materials following accidents, risks were analyzed in terms of dose and latent cancer fatalities to the public and workers. The analyses of risk also addressed the potential for fatalities that would be the direct result of mechanical forces and other nonradiological effects that occur in everyday vehicle and industrial accidents.

The transportation of spent nuclear fuel and high-level radioactive waste from the 77 sites to the Yucca Mountain site would be conducted in a manner that complied fully with regulations of the U.S. Department of Transportation and Nuclear Regulatory Commission. These regulations specify requirements that promote safety and security in transportation. The requirements apply to carrier

POTENTIAL EFFECTS OF HUMAN ERROR ON ACCIDENT IMPACTS

The accident scenarios described in this chapter would be mostly a direct consequence of error on the part of transport vehicle operators, operators of other vehicles, or persons who maintain vehicles and rights-of-way. The number and severity of the accidents would be minimized through the use of trained and qualified personnel.

Others have argued that other kinds of human error could also contribute to accident consequences: (1) undetected error in the design and certification of transportation packaging (cask) used to ship radioactive material, (2) hidden or undetected defects in the manufacture of these packages, and (3) error in preparing the packages for shipment. DOE has concluded that regulations and regulatory practices of the Nuclear Regulatory Commission and the Department of Transportation address the design, manufacture, and use of transportation packaging and are effective in preventing these kinds of human error by requiring:

- Independent Nuclear Regulatory Commission review of designs to ensure compliance with requirements (10 CFR Part 71)
- Nuclear Regulatory Commission-approved and audited quality assurance programs for design, manufacturing, and use of transportation packages

In addition, Federal provisions (10 CFR Part 21) provide additional assurance of timely and effective actions to identify and initiate corrective actions for undetected design or manufacturing defects. Furthermore, conservatism in the approach to safety incorporated in the regulatory requirements and practices provides confidence that design or manufacturing defects that might remain undetected or operational deficiencies would not lead to a meaningful reduction in the performance of a package under normal or accident conditions of transportation.

operations; in-transit security; vehicles; shipment preparations; documentation; emergency response; quality assurance; and the design, certification, manufacture, inspection, use, and maintenance of packages (casks) that would contain the spent nuclear fuel and high-level radioactive waste.

Because of the high level of performance required by regulations for transportation casks (49 CFR Part 173 and 10 CFR Part 71), the Nuclear Regulatory Commission estimates that in more than 99.99 percent of rail and truck accidents no cask contents would be released (DIRS 152476-Sprung et al. 2000, pp. 7-73 to 7-76). The 0.007 percent of accidents, including those for which there is no release and those that could cause a release of radioactive materials, can be described by a spectrum of accident severity. In general, as the severity of an accident increases, the fraction of radioactive material contents that could be released from transportation casks also increases. However, as the severity of an accident increases it is generally less likely to occur. DIRS 152476-Sprung et al. (2000, all) developed an accident analysis methodology that uses this concept of a spectrum of severe accidents to calculate the probabilities and consequences of accidents that could occur in transporting highly radioactive materials.

The analysis in DIRS 152476-Sprung et al. (2000, pp. 7-74 and 7-76), which DOE adopted for the analysis in the EIS, estimates that 0.01 percent of accidents to steel-lead-steel casks could result in some lead displacement and consequent loss of shielding. The analysis evaluated the radiological impacts (population dose risk) of shielding loss and the impacts of potential releases of radioactive material. The loss-of-shielding analysis included estimates of radiological impacts for the percentage of accidents in which there would be neither loss of shielding nor release of radioactive material. In such accidents, the vehicle carrying the spent nuclear fuel would be stopped along the route for an extended period and nearby residents would not be evacuated.

Although the approach of DIRS 152476-Sprung et al. (2000, pp. 7-7 to 7-12), which is used in this EIS, provides a method for determining the frequency with which severe accidents can be expected to occur, their severity, and their consequences, a method does not exist for predicting where along routes accidents would occur. Therefore, the analyses of impacts presented here used the approach used in RADTRAN 5 (DIRS 155430-Neuhauser, Kanipe, and Weiner 2000, all). This method assumes that accidents could occur at any location along routes, with their frequency of occurrence being determined by the accident rate characteristic of the states through which the route passes, the length of the route, and the number of shipments that travel the route.

The transportation accident scenario analysis evaluated radiological impacts to populations and to hypothetical maximally exposed individuals and estimated fatalities that could occur from traffic accidents. It included both rail and legal-weight truck transportation. The analysis used the RADTRAN 5 (DIRS 150898-Neuhauser and Kanipe 2000, all; DIRS 155430-Neuhauser, Kanipe, and Weiner 2000, all) and RISKIND (DIRS 101483-Yuan et al. 1995, all) models and computer programs to determine accident consequences and risks. DOE has used both codes in recent DOE environmental impact statements (DIRS 101802-DOE 1995, Volume 1, Appendix J; DIRS 101812-DOE 1996, Appendix E; DIRS 101816-DOE 1997, Appendixes F and G) that address impacts of transporting radioactive materials. The analyses used the following information to determine the consequences and risks of accidents for populations:

- Routes from the 77 sites to the repository and their lengths in each state and population zone
- The number of shipments that would be transported over each route
- State-specific accident rates
- The kind and amount of radioactive material that would be transported in shipments
- The type of cask used in spent nuclear fuel and high-level radioactive waste transportation
- Probabilities of amount of lead displacement that would result in loss of shielding
- Probabilities of release and fractions of cask contents that could be released in accidents
- The number of people who could be exposed to radiological material from accidents and how far they lived from the routes
- The length of time people could be exposed to external radiation in accidents that do not involve releases of radioactive material
- Exposure scenarios that include multiple exposure pathways, state-specific agricultural factors, and atmospheric dispersion factors for neutral and stable conditions applicable to the entire country for calculating radiological impacts

The analysis used the same routes and lengths of travel as the analysis of incident-free transportation impacts discussed above.

DOE used the CALVIN computer code discussed earlier, the DOE Throughput Study (DIRS 100265-CRWMS M&O 1997, all), and information provided by the DOE National Spent Nuclear Fuel Program (DIRS 104778-Jensen 1998, all) to calculate the number of shipments from each site and, thus, the number of shipments that would use a particular route.

TRANSPORTATION ACCIDENT RADIOLOGICAL DOSE RISK

The risk to the general public of radiological consequences from transportation accidents is called *dose risk* in this EIS. Dose risk is the sum of the products of the probabilities (dimensionless) and the consequences (in person-rem) of all potential transportation accidents.

The probability of a single accident is usually determined by historical information on accidents of a similar type and severity. The consequences are estimated by analysis of the quantity of radionuclides likely to be released, potential exposure pathways, potentially affected population, likely weather conditions, and other information.

As an example, the dose risk from a single accident that had a probability of 0.001 (1 chance in 1,000), and would cause a population dose of 22,000 person-rem in a population if it did occur, would be 22 person-rem. If that population was subject to 1,000 similar accident scenarios, the total dose risk would be 22,000 person-rem. Using the conversion factor of 0.0005 latent cancer fatality per person-rem, an analysis would estimate a health and safety risk of 11 latent cancer fatalities from this population dose risk.

The state-specific accident rates (accidents and fatalities per kilometer of vehicle travel) used in the analysis included accident statistics for commercial motor carrier operations for the Interstate Highway System, other U.S. highways, and state highways for each of the 48 contiguous states (DIRS 103455-Saricks and Tompkins 1999, all). The analysis also used average accident and fatality rates for railroads in each state. The data specifically reflect accident and fatality rates that apply to commercial motor carriers and railroads.

Appendix A contains information on the radioactive material contents of shipments. Appendix A, Section A.2.1.5 describes the characteristics of the spent nuclear fuel and high-level radioactive waste that would be shipped. The analysis assumed that the inventory of radioactive materials in shipments would be representative pressurized-water reactor spent nuclear fuel that had been removed from reactors for 15 years. Appendix A describes this inventory. The estimated impacts would be less if the analysis used the characteristics of a typical boiling-water reactor spent nuclear fuel, DOE spent nuclear fuel (including naval spent nuclear fuel, which the analysis assumed would be removed from reactors 5 years before its shipment to the repository), or high-level radioactive waste. Section J.1.2.1.1 describes the casks.

The analysis also used the number of people who potentially would be close enough to transportation routes at the time of an accident to be exposed to radiation or radioactive material released from casks, and the distances these people would be from the accidents. It used the HIGHWAY and INTERLINE computer programs to determine this estimated number of people and their distances from accidents. HIGHWAY and INTERLINE used 1990 Census data for this analysis. In addition, the analysis escalated impacts to account for changes in population from 1990 to 2035 using Bureau of the Census projections. The analysis assumed that the region of influence extended 80 kilometers (50 miles) from an accident involving a release of radioactive material, and 800 meters (0.5 mile) on either side of the route for accidents with no release.

Accident Severity Categories and Conditional Probabilities

For accidents involving release of radioactive material, DIRS 152476-Sprung et al. (2000, pp. 7-73 to 7-76) organizes truck and rail accident scenarios according to estimated severity, likelihood of that severity, and releases that might result. Nineteen scenarios for legal-weight truck and 21 scenarios for rail were postulated. Classification matrices were made for four generic casks and pressurized-water and boiling-water reactor commercial spent nuclear fuel types. Figures J-8a and J-8b show the classification matrices for the cask and fuel used in the analysis of impacts presented in this EIS: steel-depleted uranium-steel casks for truck shipments of pressurized-water reactor fuel and steel-lead-steel casks for rail shipments of pressurized-water reactor fuel. Use of data from DIRS 152476-Sprung et al. (2000, pp. 7-73 to 7-76) for other cask types and for boiling-water reactor spent nuclear fuel would lead to smaller impacts.

Figures J-8a and J-8b have been moved to Volume IV of this EIS.

Accident severity is a function of two variables. The first variable is the mechanical force that occurs in impacts. In the figures, mechanical force is represented by the impact velocity along the vertical axis of the matrix. The second variable is thermal energy, or the heat input to a cask engulfed by fire, also along the horizontal axis. Thermal energy is represented by the midpoint temperature of a cask's lead shield wall following heating, as in a fire.

Because all accident scenarios that would involve casks can be described in these terms, the severity of accidents can be analyzed independently of specific accident sequences. In other words, any sequence of events that results in an accident in which a cask is subjected to mechanical forces, within a certain range of values, and possibly fire is assigned to the accident severity category associated with the applicable ranges for the two parameters. This accident severity scheme enables analysis of a manageable number of accident situations while accounting for all reasonably foreseeable transportation accidents, including accidents with low probabilities but high consequences and those with high probabilities but low consequences. The scheme also encompasses by inference all scenarios that result in a particular outcome.

For the analysis of impacts, a conditional probability was assigned to each accident severity category. Figures J-8a and J-8b show the conditional probabilities developed in DIRS 152476-Sprung et al. (2000, pp. 7-73 to 7-76) for the accident severity matrix. These conditional probabilities were used in the analysis of impacts presented in this appendix. The conditional probabilities are the chances that accidents will involve the mechanical forces and the heat energy in the ranges that apply to the categories. For example, accidents that would fall into Cell 19 in the lower left corner of Figure J-8a, which represents the least severe accident in the matrix, would be likely to make up 99.993 percent of all accidents that would involve truck shipments of casks carrying spent nuclear fuel. The mechanical forces and heat in accidents in this category would not exceed the regulatory design standards for casks. Using the information in the figure, in an accident in this category the safety function of the cask would not be lost and the temperature of the cask would not change. These conditions are within the range of damage that would occur to casks subjected to the hypothetical accident conditions tests that Nuclear Regulatory Commission regulations require a cask to survive (10 CFR Part 71). Accidents in Cell 7 or Cell 12, for example, which would cause considerable damage to a cask, are very severe but very infrequent. Cell 7 accidents would occur an estimated 3 times in each 1 trillion truck accidents, and Cell 12 accidents would occur an estimated 2 times in each 100 trillion truck accidents.

The probabilities shown in each cell of Figures J-8a and J-8b are the conditional probabilities derived from event trees (for example, DIRS 152476-Sprung et al. 2000, p. 7-10) that are assigned to each severity category. These conditional probabilities are the chances that, if an accident occurs, that accident will involve the impact speed and the heat energy in the ranges that apply to the categories. The analysis of accident risks presented in this appendix used the frequency that would be likely for accidents in each of the severity categories. This frequency was determined by multiplying the category's conditional probability by the accident rates for each state's urban, suburban, and rural population zones and by the shipment distances in each of these zones, and then adding the results. The accident rates in the population density zones in each state are distinct and correspond to traffic conditions, including average vehicle speed, traffic density, and other factors, including rural, suburban, or urban location.

Accident Releases

To assess radiological consequences, cask release fractions for each accident severity category for each chemically and physically distinct radioisotope were calculated (DIRS 152476-Sprung et al. 2000, Sections 7.3 and 7.4). The *release fraction* of each isotope is the fraction of that isotope in the cask that could be released from the cask in a given severity of accident. Release fractions vary according to spent nuclear fuel type and the physical/chemical properties of the radioisotopes. Almost all of the radionuclides in spent nuclear fuel are chemically stable and do not react chemically when released. All are physically stable and most are in solid form. Gaseous radionuclides, such as krypton-85, could be released if both the fuel cladding and cask containment boundary were compromised. Volatile radionuclides, like radiocesium iodide, could be released in part, and would also deposit on the inside of the cask, depending on the temperature of the cask.

DIRS 152476-Sprung et al. (2000, p. 7-71) developed release fractions for commercial spent nuclear fuel from both boiling-water and pressurized-water reactors. Figures J-8a and J-8b provide examples of these release fractions. The analysis estimated the amount of radioactive material released from a cask in an accident by multiplying the approximate release fraction by the number of fuel assemblies in a cask (see Table J-3) and the radionuclide activity of a spent nuclear fuel assembly (see Appendix A). To provide perspective, the release fraction for a category 6 accident involving a large rail cask carrying 60 assemblies of spent boiling-water reactor fuel could result in an estimated release of about 48 curies of cesium isotopes. For this analysis, the release fractions developed by DIRS 152476-Sprung et al. (2000, pp. 7-73 to 7-76) were used for commercial pressurized-water and boiling-water reactor fuel. In addition, the analysis used release fractions for spent nuclear fuel from training, research and isotope reactors built by General Atomics (commonly called *TRIGA* spent nuclear fuel), aluminum-based fuel, uranium-carbide fuel, and vitrified high-level radioactive waste.

Accidental Loss of Shielding

Under accident conditions, a reduction in the radiation shielding provided by the spent nuclear fuel cask could occur. An accident where shielding is lost or its effectiveness reduced is often referred to as a loss of shielding accident. Shielding could be lost in high-impact collisions, which could cause lead shielding in a cask to slump towards the point of impact, or in a long-duration, intense fire, which could cause lead shielding to melt and expand. As the lead shielding cooled and solidified, it could shrink and possibly leave voids. Puncture of the cask could result in loss of melted lead. Loss of shielding can occur only in casks that use lead as shielding; it cannot occur in casks that use steel or depleted uranium for shielding.

Using the data presented in Table 8.12 from DIRS 152476-Sprung et al. (2000, pp. 8-47 to 8-50), conditional probabilities, radiation dose rates, and an exposure factor for calculating collective dose were developed for 6 accident severity categories that represent a complete spectrum of loss of shielding accidents (see Table J-19) for 4 cask types. The exposure factors were calculated using RADTRAN 5 assuming that a population from 30 to 800 meters (98 to 2,600 feet) was exposed for 12 hours. Unit risk factors were calculated by multiplying the exposure factor by the accident conditional probability. Category 1 represents accidents where there was no loss of shielding and resulting radiation dose rate and exposure factor are for an undamaged cask. This is the only category applicable to steel or depleted uranium casks. Categories 2 through 6 represent accidents that involve various impact speeds and temperatures. Table J-20 shows the relationship of the 6 accident severity categories for loss of shielding presented here to the 21 rail accident cases and 19 truck accident cases discussed in DIRS 152476-Sprung et al. (2000, pp. 7-73 through 7-76).

Table J-19. Loss-of-shielding conditional probabilities, radiation dose rates, and exposure factors for four cask types and six accident severity categories.[a]

Cask type	Conditional probability	Radiation dose rate (rem per hour)[b]	Exposure factor (person-rem per person/km^2)[c]
Steel-lead-steel rail			
Category 1	0.9999	1.4×10^{-2}	3.9×10^{-5}
Category 2	6.4×10^{-6}	8.2	7.2×10^{-3}
Category 3	4.9×10^{-5}	2.4	2.0×10^{-3}
Category 4	4.5×10^{-7}	1.3×10^{1}	1.2×10^{-2}
Category 5	2.4×10^{-5}	2.9	2.4×10^{-3}
Category 6	5.2×10^{-9}	2.4×10^{1}	3.0×10^{-2}
Steel-lead-steel truck			
Category 1	0.9999	1.4×10^{-2}	3.9×10^{-5}
Category 2	4.5×10^{-7}	1.3×10^{1}	7.1×10^{-3}
Category 3	4.9×10^{-5}	2.4	8.5×10^{-4}
Category 4	6.4×10^{-6}	8.2	3.5×10^{-3}
Category 5	2.4×10^{-5}	2.9	1.0×10^{-3}
Category 6	5.2×10^{-9}	2.4×10^{1}	2.2×10^{-2}
Monolithic rail			
Category 1	1.0000	1.4×10^{-2}	3.9×10^{-5}
Category 2	0.0	1.4×10^{-2}	3.9×10^{-5}
Category 3	0.0	1.4×10^{-2}	3.9×10^{-5}
Category 4	0.0	1.4×10^{-2}	3.9×10^{-5}
Category 5	0.0	1.4×10^{-2}	3.9×10^{-5}
Category 6	0.0	1.4×10^{-2}	3.9×10^{-5}
Steel-depleted uranium-steel rail			
Category 1	1.0000	1.4×10^{-2}	3.9×10^{-5}
Category 2	0.0	1.4×10^{-2}	3.9×10^{-5}
Category 3	0.0	1.4×10^{-2}	3.9×10^{-5}
Category 4	0.0	1.4×10^{-2}	3.9×10^{-5}
Category 5	0.0	1.4×10^{-2}	3.9×10^{-5}
Category 6	0.0	1.4×10^{-2}	3.9×10^{-5}

a. Source: Calculated by RADTRAN 5.
b. Radiation dose rate at 1 meter from the cask.
c. km^2 = square kilometer; 1 square kilometer = 0.39 square miles or 247.1 acres.

Table J-20. Grouping of accident cases into accident categories.[a]

Accident category	Rail accident cases	Truck accident cases
Category 1	21	19
Category 2	1, 7, 8, 9	2, 10, 11, 12
Category 3	20	18
Category 4	2, 10, 11, 12	1, 7, 8, 9
Category 5	4, 5, 6	4, 5, 6
Category 6	3, 13, 14, 15, 16, 17, 18, 19	3, 13, 14, 15, 16, 17

a. Source: Adapted from DIRS 152476-Sprung et al. (2000, Table 8.12).

The unit risk factor for a category was multiplied by the shipment distance, the number of shipments, the accident rate, and the population density to yield the radiation dose to the exposed population for the category. The radiation doses for all categories were summed to yield the overall radiation dose from all categories of loss of shielding accidents.

Atmospheric Conditions

For the analyses of accident risk and consequences, releases of radioactive materials from casks during and following severe accidents were assumed to be into the air where these materials would be carried by wind. Because it is not possible to predict specific locations where transportation accidents would occur, average U.S. atmospheric conditions were used.

RADTRAN 5, which DOE used in the analysis, contains embedded tables giving the "footprint" of the dispersed plume in curves of constant concentration, called isopleths, for each of the six Pasquill stability classes (DIRS 155430-Neuhauser, Kanipe, and Weiner 2000, Chapter 4). These tables incorporate wind speed, downwind distance, area of the footprint, and dilution of the plume. Dispersion of releases from an accident are then modeled by combining these tables to represent national average weather conditions. The RADTRAN 5/database combination was then used in the analysis to calculate an accident *dose risk* incorporating the risk from inhaled and ingested radioactive material, and external radiation from radioactive material deposited on the ground and suspended in the air.

Table J-21 lists the frequency at which atmospheric stability and wind speed conditions occur in the contiguous United States. The data, which are averages for 177 meteorological data collection locations, were used in conjunction with the RADTRAN 5/database to calculate the population (collective) dose risk from any accident, as well as with the RISKIND computer program (DIRS 101483-Yuan et al. 1995, all). RISKIND was used to estimate the consequences of maximum reasonably foreseeable accidents and acts of sabotage.

Table J-21. Frequency of atmospheric and wind speed conditions – U.S. averages.[a]

Atmospheric stability class	Wind speed condition						
	WS(1)	WS(2)	WS(3)	WS(4)	WS(5)	WS(6)	Total
A	0.00667	0.00444	0.00000	0.00000	0.00000	0.00000	0.01111
B	0.02655	0.02550	0.01559	0.00000	0.00000	0.00000	0.06764
C	0.01400	0.02931	0.05724	0.01146	0.00122	0.00028	0.11351
D	0.03329	0.07231	0.15108	0.16790	0.03686	0.01086	0.47230
E	0.00040	0.04989	0.06899	0.00146	0.00016	0.00003	0.12093
F	0.10771	0.08710	0.00110	0.00000	0.00000	0.00000	0.19591
G	0.01713	0.00146	0.00000	0.00000	0.00000	0.00000	0.01859
F+G	0.12485	0.08856	0.00110	0.00000	0.00000	0.00000	0.21451
Totals	*0.20576*	*0.27000*	*0.29401*	*0.18082*	*0.03825*	*0.01117*	*1.00000*
Wind speed (meters per second)[b]	0.89	2.46	4.47	6.93	9.61	12.52	

a. Source: DIRS 104800-CRWMS M&O (1999, p. 40).
b. To convert meters per second to miles per hour, multiply by 2.237.

In calculating estimated values for consequences, RISKIND used the atmospheric stability and wind speed data to analyze the dispersion of radioactive materials in the atmosphere that could follow releases in severe accidents. Using the results of the dispersion analysis, RISKIND calculated values for radiological consequences (population dose and dose to a maximally exposed individual). These results were placed in order from largest to smallest consequence. Following this order, the probabilities of the atmospheric conditions associated with each set of consequences were incorporated to provide a cumulative probability. This procedure was followed to identify the most severe accident consequences that would have a cumulative estimated annual frequency of occurrence of at least 1 in 10 million. The procedure was carried out separately for urban and rural accidents and for neutral and stable atmospheric conditions.

Exposure Pathways

Radiation doses from released radioactive material were calculated for an individual who is postulated to be near the scene of an accident and for populations within 80 kilometers (50 miles) of an accident location. Doses were determined for rural, suburban, and urban population groups. Dose calculations considered a variety of exposure pathways, including inhalation and direct exposure (cloudshine and immersion in a plume of radioactive material) from a passing cloud of contaminants; ingestion from contaminated crops; direct exposure from radioactivity deposited on the ground (groundshine); and inhalation of radioactive particles resuspended by wind from the ground.

Emergency Response, Interdiction, Dose Mitigation, and Evacuation

The RADTRAN 5 computer program that DOE used to estimate radiological risks allows the user to include assumptions about the postaccident remediation of radioactive material contamination of land where people live. The analysis using the program assumed that, after an accident, contaminants would continue to contribute to population dose through three pathways—groundshine, inhalation of resuspended particulates, and, for accidents in rural areas, ingestion of foods produced on the contaminated lands. It also assumed that medical and other interdiction would not occur to reduce concentrations of radionuclides absorbed or deposited in human tissues as a result of accidents.

For a discussion of emergency response to transportation accidents, see Appendix M, Section M.5.

Similarly, the RISKIND (DIRS 101483-Yuan et al. 1995, all) computer program includes assumptions about response, interdiction, dose mitigation, and evacuation for calculating radiological consequences (dose to populations and maximally exposed individuals). In estimating consequences of maximum reasonably foreseeable accidents during the transportation of spent nuclear fuel and high-level radioactive waste to the repository, the analysis assumed the following:

- Populations would continue to live on contaminated land for 1 year.
- There would be no radiological dose to populations from ingestion of contaminated food. Food produced on land contaminated by a maximum reasonably foreseeable accident would be embargoed from consumption.
- Medical and other interdiction would not occur to reduce concentrations of radionuclides absorbed or deposited in human tissues as a result of an accident.

The analysis of a maximum foreseeable loss-of-shielding accident assumed that the vehicle would be stopped at the site of the accident for 12 hours.

Emergency management personnel (first responders) would be between 2 and 10 meters (6.6 and 33 feet) from the vehicle for about an hour to secure the vehicle and keep people away. For about half of this time, the emergency personnel would be exposed to that section of the cask where shielding had been lost.

The analysis of radiological risks to populations and estimates of consequences of maximum reasonably foreseeable accidents did not explicitly address local, difficult-to-evacuate populations such as those in prisons, hospitals, nursing homes, or schools. However, the analysis addressed the potential for accidents to occur in urban areas with high population densities and used the assumptions regarding interdiction, evacuation, and other intervention actions discussed above. These assumptions encompass the consequences and risks that could arise as a result of time to implement measures to mitigate the consequences for some population groups.

Health Risk Conversion Factors

The health risk conversion factors used to estimate expected latent cancer fatalities from radiological exposures are presented in International Commission on Radiological Protection Publication 60 (DIRS 101836-ICRP 1991, p. 22). These factors are 0.0005 latent cancer fatality per person-rem for members of the public and 0.0004 latent cancer fatality per person-rem for workers. For accidents in which individuals would receive doses greater than 20 rem over a short period (high dose/high dose rate), the factors would be 0.0010 latent cancer fatality per rem for a member of the public and 0.0008 latent cancer fatality per rem for workers.

Assessment of Accident Risk

The RADTRAN 5 database (DIRS 155430-Neuhauser, Kanipe, and Weiner 2000, all) was used in calculating risks from transportation of spent nuclear fuel and high-level radioactive waste. The code calculated unit-risk factors (person-rem per person per square kilometer per curie) for the radionuclides of concern in the inventory being shipped (see Appendix A). The unit-risk factors from RADTRAN 5 were combined with conditional accident probabilities, state-specific accident rates, release fractions for each of the six accident severity categories, for each mode of transportation, cask, and spent nuclear fuel or high-level radioactive waste form. For each site traversed, results of this analysis were combined with urban, suburban, and rural distances and population densities, and with the number of shipments. Ingestion dose risks were calculated separately by combining conditional accident probabilities, state-specific accident rates, release fractions for each of the six accident severity collective categories, and rural distances and numbers of shipments for each state with the state-specific food transfer factors. The accident dose risks were estimated in terms of collective radiation dose to the population within 80 kilometers (50 miles).

The analysis first calculated unit risk factors for a shipment. This was done for the three types of population zones in each state and for each accident severity category. The unit risk factors were for one person per square kilometer per kilometer of route traveled. The unit risk factors were multiplied by the population densities (based on 1990 Census data) along the routes. These population densities are modeled as being within 800 meters (0.5 mile) of the routes. The accident dose risk calculation then assumed that the population density in the 800-meter band along the route is the same out to 80 kilometers (50 miles) from the route and multiplies the unit risk factor by this population density, yielding a dose risk in person-rem per kilometer of route for each transportation mode, for each type of impact, and for each state through which a shipment would pass. The resultant dose risks (person-rem per kilometer) for all the applicable accident severity categories were summed for each population zone for each state. Also, for the three types of population zone in a state, the lengths through areas of each type were summed for the route used in the analysis. This yielded route lengths for each population zone in each state. The sum of the route lengths and the sum of the dose risks per kilometer for each population zone were multiplied together. This was repeated for each population zone in each state through which a shipment would pass. The resulting impacts were then multiplied by a scaling factor that is the ratio of the population in a state based on the 1990 Census to projected population in 2035. The results were summed to provide estimates of the accident dose risk (in person-rem) for a shipment.

Estimating Consequences of Maximum Reasonably Foreseeable Accident Scenarios

In addition to analyzing the radiological and nonradiological risks that would result from the transportation of spent nuclear fuel and high-level radioactive waste to the repository, DOE assessed the consequences of maximum reasonably foreseeable accidents using the analysis from DIRS 152476-Sprung et al. (2000, pp. 7-30 to 7-70) for releases of material from a spent nuclear fuel cask during an accident. This analysis provided information about the magnitude of impacts that could result from the most severe accident that could reasonably be expected to occur, although it could be highly unlikely. DOE concluded that, as a practical matter, events with a probability less than 1×10^{-7} (1 chance in 10 million) per year rarely need to be examined (DIRS 104601-DOE 1993, p. 28). This would be equivalent to about once in the course of 15 billion legal-weight truck shipments. For perspective, an accident this severe in commercial truck transportation would occur about once in 50 years on U.S. highways. Thus, the analysis of maximum reasonably foreseeable accidents postulated to occur during the transportation of spent nuclear fuel and high-level radioactive waste evaluated only consequences for accidents with a probability greater than 1×10^{-7} per year. The consequences were determined for atmospheric conditions that could prevail during accidents and for physical and biological pathways that would lead to exposure of members of the public and workers to radioactive materials and ionizing radiation. The analysis used the RISKIND code (DIRS 101483-Yuan et al. 1995, all) to estimate doses for individuals and populations. In addition to the accidents with a probability greater than 1×10^{-7} per year, the analysis estimated the consequences from all accident severity categories presented in DIRS 152476-Sprung et al. (2000, pp. 7-73 and 7-76) for a steel-depleted uranium-steel truck cask and a steel-lead-steel rail cask. The following list describes those severity categories:

Rail Accident Descriptions

- *Case 20:* Case 20 is a long-duration (many hours), high-temperature fire that would engulf a cask. Conditions reported in the Baltimore Sun Times for the Baltimore Tunnel Fire (DIRS 156753-Ettlin 2001, all; DIRS 156754-Rascovar 2001, all), which occurred in July 2001—a fire of 820ºC (1,500ºF) that burned for up to 5 days—would be similar to the conditions for a Case 20 accident.

- *Cases 19, 18, 17, and 16:* Case 19 is a high-speed (more than 120 miles per hour) impact into a hard object such as a train locomotive severe enough to cause failure of cask seals and puncture through the cask's shield wall. The impact would be followed by a very long duration (many hours), high-temperature engulfing fire. Case 18, Case 17, and Case 16 are accidents that would also involve very long duration fires, failures of cask seals, and puncture of cask walls. However, these accidents would be progressively less severe in terms of impact speeds. The impact speeds range from 90 to 120 miles for Case 18, 60 to 90 miles per hour for Case 17, and 30 to 60 miles per hour for Case 16.

- *Cases 15, 12, 9, and 6:* Case 15 is a high-speed (more than 120 miles per hour) impact into a hard surface such as granite severe enough to cause failure of cask seals. The impact would be followed by a long duration (many hours), high-temperature engulfing fire. Case 12, Case 9, and Case 6 are also accidents that would involve long duration fires, and failures of cask seals. However, these accidents would be progressively less severe in terms of impact speeds ranging from 90 to 120 miles for Case 12, 60 to 90 miles per hour for Case 9, and 30 to 60 miles per hour for Case 6.

- *Cases 14, 11, 8, and 5:* Case 14 is a high-speed (more than 120 miles per hour) impact into a hard surface such as granite severe enough to cause failure of cask seals. The impact would be followed by a high-temperature engulfing fire that burned for hours. Case 11, Case 8, and Case 5 are also accidents that would involve fires that would burn for hours, and failures of cask seals. However, these accidents would be progressively less severe in terms of impact speeds ranging from 90 to 120 miles for Case 11, 60 to 90 miles per hour for Case 8, and 30 to 60 miles per hour for Case 5.

- *Cases 13, 10, 7, and 4:* Case 13 is a high-speed (more than 120 miles per hour) impact into a hard surface such as granite severe enough to cause failure of cask seals. The impact would be followed by an engulfing fire lasting more than ½ hour up to a few hours. Case 10, Case 7, and Case 4 are accidents that would involve long duration fires, and failures of cask seals. However, these accidents are progressively less severe in terms of impact speeds ranging from 90 to 120 miles for Case 10, 60 to 90 miles per hour for Case 7, and 30 to 60 miles per hour for Case 4. An accident involving the impact of a jet engine from a passenger aircraft on a rail cask would be no more severe than a Case 4 accident (DIRS 157210-BSC 2001, all).

- *Cases 3, 2, and 1:* Case 3 is a high-speed (more than 120 miles per hour) impact into a hard surface such as granite severe enough to cause failure of cask seals—no fire. Case 2 and Case 1 are accidents that would also not involve fire but would have progressively lower impact speeds - 90 to 120 miles for Case 2 and 60 to 90 miles per hour for Case 1.

Truck Accident Descriptions

- *Case 18:* Case 18 is a long-duration (many hours), high-temperature fire that would engulf a cask. Conditions reported in the Baltimore Sun Times for the Baltimore Tunnel Fire (DIRS 156753-Ettlin 2001, all; DIRS 156754-Rascovar 2001, all), which occurred in July 2001—a fire of 820ºC (1,500ºF) that burned for up to 5 days—would be similar to the conditions for a Case 18 accident.

- *Cases 17, 16, 15, and 14:* Case 17 is a high-speed (more than 120 miles per hour) impact into a hard object such as a train locomotive severe enough to cause failure of cask seals and puncture through the cask's shield wall. The impact would be followed by a very long duration (many hours), high-temperature engulfing fire. Case 16, Case 15, and LST 14 are accidents that would also involve very long duration fires, failures of cask seals, and puncture of cask walls. However, these accidents would be progressively less severe in terms of impact speeds. The impact speeds range from 90 to 120 miles for Case 16, 60 to 90 miles per hour for Case 15, and 30 to 60 miles per hour for Case 14.

- *Cases 13, 10, 7, and 4:* Case 13 is a high-speed (more than 120 miles per hour) impact into a hard surface such as granite severe enough to cause failure of cask seals. The impact would be followed by a long duration (many hours), high-temperature engulfing fire. Case 10, Case 7, and Case 4 are also accidents that would involve long duration fires, and failures of cask seals. However, these accidents would be progressively less severe in terms of impact speeds ranging from 90 to 120 miles for Case 10, 60 to 90 miles per hour for Case 7, and 30 to 60 miles per hour for Case 4.

- *Cases 12, 9, 6, and 3:* Case 12 is a high-speed (more than 120 miles per hour) impact into a hard surface such as granite severe enough to cause failure of cask seals. The impact would be followed by a high-temperature engulfing fire that burned for hours. Case 9, Case 6, and Case 3 are also accidents that would involve fires that would burn for hours, and failures of cask seals. However, these accidents would be progressively less severe in terms of impact speeds ranging from 90 to 120 miles for Case 9, 60 to 90 miles per hour for Case 6, and 30 to 60 miles per hour for Case 3.

- *Cases 11, 8, 5, and 2:* Case 11 is a high-speed (more than 120 miles per hour) impact into a hard surface such as granite severe enough to cause failure of cask seals. The impact would be followed by an engulfing fire lasting more than ½ hour up to a few hours. Case 8, Case 5, and Case 2 are accidents that would involve long duration fires, and failures of cask seals. However, these accidents are progressively less severe in terms of impact speeds ranging from 90 to 120 miles for Case 8, 60 to 90 miles per hour for Case 5, and 30 to 60 miles per hour for Case 2. An accident involving the impact of a jet engine from a passenger aircraft on a truck cask would be no more severe than any Case 11 accident (DIRS 157210-BSC 2001, all).

- *Case 1:* Case 1 is a high-speed (more than 120 miles per hour) impact into a hard surface such as granite severe enough to cause failure of cask seals—no fire.

The analysis assumed maximum reasonably foreseeable accident scenarios could occur anywhere, either in rural or urbanized areas. The probability of such an accident would depend on the amount of exposure to the transportation accident environment. In this case, exposure would be the product of the cumulative shipment distance and the applicable accident rates. However, because of large differences in exposure, principally because of the large differences in the distances traveled in the two types of population areas, a severe accident scenario that might be reasonably foreseeable in a rural area might not be reasonably foreseeable in an urbanized area. Thus, a reasonably foreseeable accident postulated to occur in a rural area (most travel would occur in rural areas), under meteorological conditions that would be exceeded (resulting in greater consequences) only 5 percent of the time, might not be reasonably foreseeable in an urbanized area where shipments would travel relatively few kilometers. Table J-22 lists the probabilities and consequences of severe rail cask accidents during national transportation based on the analysis of releases from spent fuel casks presented in DIRS 152476-Sprung et al. (2000, pp. 7-75 to 7-76) for urban

Table J-22. Frequency and consequence of rail accidents.[a]

Rail cask					
Case	Expected frequency	Total exposure (person-rem)	Case	Expected frequency	Total exposure (person-rem)
Urban Area - Stability Class F			Rural Area - Stability Class F		
19	7.67×10^{-19}	254,377	19	4.71×10^{-18}	419
15	7.67×10^{-16}	254,377	15	4.71×10^{-15}	419
14	5.77×10^{-15}	242,817	14	3.54×10^{-14}	400
13	2.07×10^{-13}	230,214	13	1.27×10^{-12}	379
16	2.32×10^{-12}	220,788	16	1.43×10^{-11}	364
3	2.51×10^{-11}	219,698	3	1.54×10^{-10}	361
18	9.74×10^{-17}	173,447	18	5.99×10^{-16}	285
12	9.74×10^{-14}	173,447	12	5.99×10^{-13}	285
11	7.34×10^{-13}	171,358	11	4.51×10^{-12}	282
6	6.16×10^{-10}	159,807	6	3.78×10^{-9}	264
10	2.62×10^{-11}	149,279	10	1.61×10^{-10}	246
2	3.18×10^{-9}	149,266	2	1.95×10^{-8}	245
17	1.41×10^{-15}	112,468	17	8.63×10^{-15}	185
9	1.41×10^{-12}	81,049	9	8.63×10^{-12}	134
20	2.75×10^{-7}	9,893	20	1.69×10^{-6}	16.3
8	1.05×10^{-11}	3,416	8	6.47×10^{-11}	5.63
7	3.79×10^{-10}	3,060	7	2.33×10^{-9}	5.04
1	4.59×10^{-8}	2,933	1	2.82×10^{-7}	4.83
5	4.61×10^{-9}	1,745	5	2.83×10^{-8}	2.88
4	1.66×10^{-7}	1,346	4	1.02×10^{-6}	2.22

a. Source: DIRS 152476-Sprung et al. (2000, p. 7-75).

area and rural area population and stability class F weather conditions. Stability class D consequences were analyzed but, because the consequences are smaller than those of class F stability conditions, they are not presented. Similarly, Table J-23 lists the probabilities and consequences of severe truck accidents for stability class F conditions.

For the mostly rail scenario, legal-weight truck accidents would not be reasonably foreseeable. For rail accidents, the severity case, which is reasonably foreseeable and would have the greatest consequences, is Case 20 with an expected frequency of 2.8×10^{-7} and consequences of 9,900 person-rem.

For the mostly legal-weight truck scenario, in which only naval spent nuclear fuel would be shipped by rail, the likelihood would be less than 1×10^{-7} per year for the most severe rail accident to occur in an urbanized area. Thus, the highest severity rail accidents would only be reasonably foreseeable in rural areas under average (50-percent) meteorological conditions (probability greater than 1 in 10 million per year). For truck accidents in urban areas, the severity case, which is reasonably foreseeable and has the greatest consequences, is Case 18 with an expected frequency of 2.3×10^{-7} and consequences of 1,100 person-rem.

The analysis of maximum reasonably foreseeable accidents evaluated all the accidents for steel-depleted uranium-steel truck and steel-lead-steel rail casks from DIRS 152476-Sprung et al. (2000, pp. 7-73 and 7-76). However, only accidents from Tables J-22 and J-23 that have an expected frequency greater than 1×10^{-7} would be reasonably foreseeable.

Table J-24 summarizes the accidents with the greatest consequences that would be reasonably foreseeable. Although stability class D accidents are reasonably foreseeable, the consequences from stability class F accidents would be greater as listed in Table J-24.

Table J-23. Frequency and consequence of truck accidents.[a]

Case	Expected frequency	Total exposure (person-rem)	Case	Expected frequency	Total exposure (person-rem)
Truck cask					
Urban Area - Stability Class F			Rural Area - Stability Class F		
14	2.8×10^{-12}	36,798	14	1.6×10^{-11}	60.7
15	1.3×10^{-16}	18,919	15	7.6×10^{-16}	31.1
4	2.8×10^{-9}	8,484	4	1.6×10^{-8}	14
7	1.3×10^{-13}	5,203	7	7.6×10^{-13}	8.57
12	9.8×10^{-16}	1,251	12	5.5×10^{-15}	2.07
9	7.7×10^{-14}	1,251	9	4.4×10^{-13}	2.07
11	6.0×10^{-12}	1,146	11	3.4×10^{-11}	1.88
8	4.7×10^{-10}	1,146	8	2.7×10^{-9}	1.88
1	6.2×10^{-10}	1,125	1	3.5×10^{-9}	1.85
18	2.3×10^{-7}	1,083	18	1.3×10^{-6}	1.79
6	3.7×10^{-12}	723	6	2.1×10^{-11}	1.19
5	2.0×10^{-8}	581	5	1.1×10^{-7}	0.92
3	1.1×10^{-8}	291	3	6.4×10^{-8}	0.48
2	2.5×10^{-6}	225	2	1.4×10^{-5}	0.37
17	0	N/A[b]	17	0	N/A[b]
16	0	N/A	16	0	N/A
13	0	N/A	13	0	N/A
10	0	N/A	10	0	N/A

a. Source: DIRS 152476-Sprung et al. (2000, p. 7-74).
b. N/A = not applicable, because probability is zero.

Table J-24. Consequences (person-rem) of maximum reasonably foreseeable accidents in national transportation.[a]

Case	Urban (person-rem)	Rural (person-rem)	MEI (rem)[b]
Rail (Case 20)	9,893	16	29
Truck (Case 18)	1,083	2	3

a. All accidents are modeled in with stability class F conditions.
b. MEI = maximally exposed individual.

The analysis of consequences of maximum reasonably foreseeable accidents used data from the 1990 census escalated to 2035 to estimate the size of populations in urbanized areas that could receive exposures to radioactive materials. The analysis used estimated populations in successive 8-kilometer (5-mile)-wide annular rings around the centers of the 21 large urbanized areas (cities and metropolitan areas) in the continental United States (DIRS 104800-CRWMS M&O 1999, p. 22).

The average population for each ring was used to form a population distribution for use in the analysis. To be conservative in estimating consequences, the analysis assumed that accidents in urbanized areas would occur at the center of the population zone, where the population density would be greatest. This assumption resulted in conservative estimates of collective dose to exposed populations.

J.1.4.2.2 *Methods and Approach for Analysis of Nonradiological Impacts of Transportation Accidents*

Nonradiological accident risks are risks of traffic fatalities. Traffic fatality rates are reported by state and Federal transportation departments as fatalities per highway vehicle- or train-kilometer traveled. The fatalities are caused by physical trauma in accidents. For nonradiological accident risks estimated in this

EIS for legal-weight truck transportation, accident fatality risks were based on state-level fatality rates for Interstate Highways (DIRS 103455-Saricks and Tompkins 1999, all). Accident fatality risks for rail transportation were also calculated using state-specific rates (DIRS 103455-Saricks and Tompkins 1999, all). Section J.2.2 discusses methods and data used to analyze accidents for barge transportation.

For truck transportation, the rates in DIRS 103455-Saricks and Tompkins (1999, Table 4) are specifically for heavy combination trucks involved in interstate commerce. Heavy combination trucks are multiaxle tractor-trailer trucks having a tractor and one to three freight trailers connected to each other. This kind of truck with a single trailer would be used to ship spent nuclear fuel and high-level radioactive waste. Truck accident rates were determined for each state based on statistics compiled by the U.S. Department of Transportation Office of Motor Carriers for 1994 through 1996. The report presents accident involvement and fatality counts, estimated kilometers of travel by state, and the corresponding average accident involvement, fatality, and injury rates for the 3 years investigated. Fatalities include crew members and all others attributed to accidents. Although escort vehicles would not be heavy combination trucks, the fatality rate data used for truck shipments of loaded and empty spent fuel casks were also used to estimate fatalities from accidents that would involve escort vehicles.

Rail accident rates were computed and presented similarly to truck accident rates, but a railcar is the unit of haulage. The state-specific rail accident involvement and fatality rates are based on statistics compiled by the Federal Railroad Administration for 1994 through 1996. Rail accident rates include both mainline accidents and those occurring in railyards. The per-railcar rate in DIRS 103455-Saricks and Tompkins (1999, Table 6) was multiplied by 4.2, the average number of railcars involved in an accident.

The accident rates used to estimate traffic fatalities were computed using data for all interstate shipments, independent of the cargoes. Shippers and carriers of radioactive material generally have a higher-than-average awareness of transport risk and prepare cargoes and drivers accordingly (DIRS 101920-Saricks and Kvitek 1994, all). These effects were not given credit in the assessment.

J.1.4.2.3 *Data Used To Estimate Incident Rates for Rail and Motor Carrier Accidents*

In analyzing potential impacts of transporting spent nuclear fuel and high-level radioactive waste, DOE considered both incident-free transportation and transportation accidents. Potential incident-free transportation impacts would include those caused by exposing the public and workers to low levels of radiation and other hazards associated with the normal movement of spent nuclear fuel and high-level radioactive waste by truck, rail, or barge. Impacts from accidents would be those that could result from exposing the public and workers to radiation, as well as vehicle-related fatalities.

In its analysis of impacts from transportation accidents, DOE relied on data collected by the U.S. Department of Transportation and others (for example, the American Petroleum Institute) to develop estimates of accident likelihood and their ranges of severity (DIRS 101828-Fischer et al. 1987, pp. 7-25 and 7-26). Using these data, the analysis estimated that as many as 66 accidents could occur over 24 years in the course of shipping spent nuclear fuel to the repository by legal-weight trucks; 8 rail accidents that involved a railcar carrying a cask could occur if most shipments were by rail; and no accidents would be likely for the limited use of barges.

Furthermore, in using data collected by the U.S. Department of Transportation, the analysis considered the range of accidents, from slightly more than “fender benders” to high-speed crashes, that the DOE carrier would have to report in accordance with the requirements of U.S. Department of Transportation regulations. The accidents that could occur would be unlikely to be severe enough to affect the integrity of the shipping casks.

The following paragraphs discuss reporting and definitions for transportation accidents and the relationships of these to data used in analyzing transportation impacts in this EIS.

J.1.4.2.3.1 Transportation Accident Reporting and Definitions. In the United States, the reporting of transportation accidents and incidents involving trucks, railroads, and barges follows requirements specified in various Federal and state regulations.

Motor Carrier Accident Reporting and Definitions

Regulations generally require the reporting of motor carrier accidents (regardless of the cargo being carried) if there are injuries, fatalities, or property damage. These regulations have evolved through the years, mostly in response to increasing values of transportation equipment and commodities. For example, the Federal requirements in the following text box establish a functional threshold for damage to vehicles rather than a value-of-damage threshold, which was used until the 1980s. Nonetheless, many states continue to use value thresholds (for example, Ohio uses $500) for vehicle damage when documenting reportable accidents.

Until March 4, 1993, Federal regulations (49 CFR Part 394) required motor carriers to submit accident reports to the Federal Highway Administration Motor Carrier Management Information System using the so-called “50-T” reporting format. The master file compiled from the data on these reports in the Federal Highway Administration Office of Motor Carriers was the basis of accident, fatality, and injury rates developed for the 1994 study of transportation accident rates (DIRS 101920-Saricks and Kvitek 1994, all).

The Final Rule (58 *FR* 6726; February 2, 1993) modified the carrier reporting requirement; rather than submitting reports, carriers now must maintain a register of accidents that meet the definition of an accident for 1 year after such an accident occurs. Carriers must make the contents of such a register available to Federal Highway Administration agents investigating specific accidents. They must also give “…all reasonable assistance in the investigation of any accident including providing a full, true, and correct answer to any question of inquiry” to determine if hazardous materials other than spilled fuel from the fuel tanks were released, and to furnish copies of all state-required accident reports (49 CFR 390.15). The reason for this rule change was the emergence of an automated State accident reporting system compiled from law enforcement accident reports that, pursuant to provisions of the Intermodal Surface Transportation Efficiency Act of 1991 (Public Law 102-240, 105 Stat. 1914), was established under the Motor Carrier Safety Assistance Program.

Under Section 408 of Title IV of the Motor Carrier Act of 1991 (Public Law 102-240, 105 Stat. 2140), a component of the Intermodal Surface Transportation Efficiency Act, the Secretary of Transportation is authorized to make grants to states to help them achieve uniform implementation of the police reporting system for truck and bus accidents recommended by the National Governors Association. Under this system, called SAFETYNET, accident data records generated by each state follow identical formatting and content instructions. They are entered in a Federally maintained SAFETYNET database on approximately a weekly basis. The SAFETYNET database, in turn, is compiled and managed as part of the Motor Carrier Management Information System.

Because DIRS 152476-Sprung et al. (2000, all) is the fundamental source for data that describes the severity of transportation accidents used in this EIS, the relative constancy of the definition of *accident* is important in establishing confidence in estimated impact results. Thus, although the transportation environment has changed over the 40 years of data collection, the constancy of the definition of *accident* tends to provide confidence that the distribution of severity for reported accidents has remained relatively the same. That is, low-consequence, fender-bender accidents are the most common, high-consequence, highly energetic accidents are rare, and the proportions of these have remained roughly the same.

COMMERCIAL MOTOR VEHICLE ACCIDENT
(49 CFR 390.5)

An occurrence involving a commercial motor vehicle operating on a public road in interstate or intrastate commerce that results in:

- A fatality
- Bodily injury to a person who, as a result of the injury, immediately receives medical treatment away from the scene of the accident
- One or more motor vehicles incurring disabling damage as a result of the accident, requiring the motor vehicle to be transported away from the scene by a tow truck or other motor vehicle

The term accident does not include:

- An occurrence involving only boarding and alighting from a stationary motor vehicle
- An occurrence involving only the loading or unloading of cargo
- An occurrence in the course of the operation of a passenger car or a multipurpose passenger vehicle by a motor carrier and is not transporting passengers for hire or hazardous materials of a type and quantity that require the motor vehicle to be marked or placarded in accordance with 49 CFR 177, Subpart 823

Changes in the transportation environment, such as changes in speed limits and safety technology, tend to change the accident rate (accidents per vehicle-kilometer of travel). Overall, however, given that the definition of *accident* does not change, such changes do not greatly affect the distribution of accident severities. For example, recent increases in speed limits from 105 to 121 kilometers (65 to 75 miles) per hour represent about a 25-percent increase in the maximum mechanical energy of vehicles. Other information aside, this increase could lead to the conclusion that the resulting distribution of accidents would show an increase for the most severe accidents in comparison to minor accidents. However, the speed limit increases do not represent a corresponding increase in actual traffic speeds, and would be unlikely to change the distribution of velocities and, thus, mechanical energies, of severe accidents from those reported in DIRS 152476-Sprung et al. (2000, all), which ranged to faster than 193 kilometers (120 miles) per hour.

Rail Carrier Accident Reporting and Definitions

As with regulations governing the reporting of motor carrier accidents, Federal Railroad Administration regulations generally require the reporting of accidents if there are injuries, fatalities, or property damage. These regulations have evolved through the years, mostly in response to increasing values of transportation equipment and commodities. For example, the Federal requirements in the following text box establish a value-based reporting threshold for damage to vehicles; the value has been indexed to inflation since 1975.

Rail carriers covered by these requirements must fulfill several bookkeeping tasks. The Federal Railroad Administration requires the submittal of a monthly status report, even if there were no reportable events during the period. This report must include accidents and incidents, and certain types of incidents require immediate telephone notification. Logs of reportable injuries and on-track incidents must be maintained by the railroads on which they occur, and a listing of such events must be posted and made available to employees and to the Federal Railroad Administration, along with required records and reports, on request. The data entries extracted from the reporting format are consolidated into an accident/incident database that separates reportable *accidents* from grade-crossing *incidents*. These are processed annually into event, fatality, and injury count tables in the Federal Railroad Administration's *Accident/Incident Bulletin* (DIRS 103455-Saricks and Tompkins 1999, all), which the Office of Safety publishes on the Internet (*safetydata.fra.dot.gov/officeofsafety*).

RAILROAD ACCIDENT/INCIDENT
(49 CFR 225.11)

- An impact between railroad on-track equipment and an automobile, bus, truck, motorcycle, bicycle, farm vehicle or pedestrian at a highway-rail grade crossing
- A collision, derailment, fire, explosion, act of God, or other event involving operation of railroad on-track equipment (standing or moving) that results in reportable damages greater than the current reporting threshold to railroad on-track equipment, signals, track, track structures, and roadbed
- An event arising from the operation of a railroad which results in:
  - Death to any person
  - Injury to any person that requires medical treatment
  - Injury to a railroad employee that results in:
    - A day away from work
    - Restricted work activity or job transfer
    - Loss of consciousness
    - Occupational illness

In contrast to the regulations for motor carriers discussed above, the Federal Railroad Administration regulations cited above call for the reporting of accidents and incidents. The Administration defines an *accident* as "an event involving on-track railroad equipment that results in damage to the railroad on-track equipment, signals, track, or track structure, and roadbed at or exceeding the dollar damage threshold" (49 CFR 225.11). Train *incidents* are defined as "events involving on-track railroad equipment [and non-train incidents arising from the operation of a railroad] that result in the reportable death and/or injury or illness of one or more persons, but do not result in damage at or beyond the damage threshold" (49 CFR 225.11). Because damage to casks containing spent nuclear fuel will necessarily involve severe accidents (hence, substantial damage), DIRS 152476-Sprung et al. (2000, all) used only train accidents to form the basis for developing the conditional probabilities of accident severities.

As with motor carrier operations, the constancy of the definition of a train accident is important in establishing confidence in the impact. For rail accidents the transportation environment has not changed dramatically over the years of data collection, and the definition of *accident* has remained essentially unchanged (with adjustments for inflation). The constancy of the definition provides confidence that the distribution of severity for reported accidents has remained relatively the same—low-consequence, limited-damage accidents are the most common and high-consequence, highly energetic accidents are rare, and their proportions have remained about the same. Changes in the rail transportation environment, as in safety and operations technology (for example, shelf-type couplers and tankcar head protection), have resulted in lower accident rates (per railcar-kilometer of travel) and, in some cases, less severe accidents. However, because the definition of *accident* has not changed appreciably, the changes that have occurred are not the kind that would greatly affect the relative proportions of minor and severe accidents.

Reporting and Definitions for Marine Casualties and Incidents

As with the regulations governing the reporting of motor carrier and rail accidents, U.S. law (46 U.S.C. 6101 to 6103) requires operators to report marine casualties and incidents if there are injuries, fatalities, or property damage. In addition, the law requires the reporting of significant harm to the environment.

MARINE CASUALTY AND INCIDENT
(46 U.S.C. 6101 to 6103)

Criteria have been established for the required reporting (by vessel operators and owners) of marine casualties and incidents involving all United States flag vessels occurring anywhere in the world and any foreign flag vessel operating on waters subject to the jurisdiction of the United States. An incident must be reported within five days if it results in:

- The death of an individual
- Serious injury to an individual
- "Material" loss of property (threshold not specified; previously was $25,000)
- Material damage affecting the seaworthiness or efficiency of the vessel
- Significant harm to the environment

The states collect casualty data for incidents occurring in navigable waterways within their borders, and there is a uniform state marine casualty reporting system for transmitting these reports to Federal jurisdiction (the U.S. Coast Guard). Coast Guard Headquarters receives quarterly extracts of the Marine Safety Information System developed from these sources. This system is a network database into which Coast Guard investigators enter cases at each marine safety unit. The analysis uses a Relational Database Management System. The Coast Guard Office of Investigations and Analysis compiles and processes the casualty reports into the formats and partitioned data sets that comprise the Marine Safety Information System database, which includes maritime accidents, fatalities, injuries, and pollution spills dating to 1941 (however, the file is complete only from about 1991 to the present).

Hazardous Material Transportation Accident and Incident Reporting and Definitions

Radioactive material is a subset of the more general term *hazardous material*, which includes commodities such as gasoline and chemical products. The U.S. Department of Transportation Office of Hazardous Materials estimates that there are more than 800,000 hazardous materials shipments per day, of which about 7,700 shipments contain radioactive materials.

Hazardous materials transportation regulations (49 CFR 171) contain no distinction between an *accident* and an *incident*, and *incident* is the term used to describe situations that must be reported. Hazardous materials regulations (49 CFR 171.15) require the reporting of incidents if:

- A person is killed
- A person receives injuries requiring hospitalization
- The estimated property damage is greater than $50,000
- An evacuation of the public occurs lasting one or more hours
- One or more major transportation arteries are closed or shutdown for one or more hours
- The operational flight pattern or routine of an aircraft is altered
- Fire, breakage, spillage, or suspected radioactive contamination occurs involving shipment of radioactive material
- Fire, breakage, spillage, or suspected contamination occurs involving shipment of infectious agents

- There has been a release of a marine pollutant in a quantity exceeding 450 liters (about 120 gallons) for liquids or 400 kilograms (about 880 pounds) for solids

- There is a situation that, in the judgement of the carrier, should be reported to the U.S. Department of Transportation even though it does not meet the above criteria

These criteria apply to loading, unloading, and temporary storage, as well as to transportation. The criteria involving infectious agents or aircraft are unlikely to be used for spent nuclear fuel or high-level radioactive waste shipments. Based on these criteria, reportable motor vehicle and rail transportation situations are far more exclusionary than hazardous material situations.

Carriers (not law enforcement officials) are required to report hazardous materials incidents to the U.S. Department of Transportation. These reports are compiled in the Hazardous Materials Incident Report database. In addition, U.S. Nuclear Regulatory Commission regulations (10 CFR 20.2201, 20.2202, 20.2203) require the reporting of a loss of radioactive materials, exposure to radiation, or release of radioactive materials.

Sandia National Laboratories maintains the Radioactive Materials Incident Report database, which contains incident reports from the Hazardous Materials Incident Report database that involve radioactive material. In addition, the Radioactive Materials Incident Report database contains data from the U.S. Nuclear Regulatory Commission, state radiation control offices, the DOE Unusual Occurrence Report database, and media coverage of radioactive materials transportation incidents. DIRS 101802-DOE (1995, Volume 1, Appendix I, pp. I-117) and DIRS 102172-McClure and Fagan (1998, all) discuss historic incidents involving spent nuclear fuel that are reported in the Radioactive Materials Incident Report database as well as incidents that took place prior to the existence of this database. The database characterizes incidents in three categories: transportation accidents, handling accidents, and reported incidents. However, the definitions of these categories are not consistent with the definitions used in other U.S. Department of Transportation databases. For example, from 1971 through 1998, the Radioactive Materials Incident Report database lists one transportation accident involving a loaded rail shipment of spent nuclear fuel. However, based on current Federal Railroad Administration reporting requirements, this occurrence probably would be listed as a grade-crossing incident, not an accident. For this reason and because of the small number of occurrences in the database involving spent nuclear fuel, the EIS analysis did not use the Radioactive Materials Incident Report database to estimate transportation accident rates.

J.1.4.2.3.2 Accident Rates for Transportation by Heavy-Combination Truck, Railcar, and Barge in the United States. DIRS 103455-Saricks and Tompkins (1999, all) developed estimates of accident rates for heavy-combination trucks, railcars, and barges based on data available for 1994 through 1996. The estimates provide an update for accident rates published in 1994 (DIRS 101920-Saricks and Kvitek 1994, all) that reflected rates from almost a decade earlier.

Rates for Accidents in Interstate Commerce for Heavy-Combination Trucks

DIRS 103455-Saricks and Tompkins (1999, all) developed basic descriptive statistics for state-specific rates of accidents involving interstate-registered combination trucks for 1994, 1995, and 1996. The accident rate over all road types for 1994 was 2.98×10^{-7} accident per truck-kilometer (DIRS 103455-Saricks and Tompkins 1999, Table 3a); for 1995 it was 2.97×10^{-7} accident per truck-kilometer (DIRS 103455-Saricks and Tompkins 1999, Table 3b); and for 1996 it was 3.46×10^{-7} accident per truck-kilometer (DIRS 103455-Saricks and Tompkins 1999, Table 3c). The composite mean from 1994 through 1996 was 3.21×10^{-7} accident per truck-kilometer.

During the 24 years of the Proposed Action, the *mostly legal-weight truck* national transportation scenario would involve about 53,000 truck shipments of spent nuclear fuel and high-level radioactive waste.

Based on the data in DIRS 103455-Saricks and Tompkins (1999, Table 4), the transportation analysis estimated that those shipments could involve as many as 66 accidents. During the same period, the *mostly rail* scenario would involve about 1,100 truck shipments, and the analysis estimated that as many as one truck accident could occur during these shipments. More than 99.99 percent of these accidents would not generate forces capable of causing functional damage to the casks, and would have no radiological consequences. A small fraction of the accidents could generate forces capable of damaging the cask.

Rates for Freight Railcar Accidents

Results for accident rates for freight railcar shipments from DIRS 103455-Saricks and Tompkins (1999, all), show that domestic rail freight accidents, fatalities, and injuries on Class 1 and 2 railroads have remained stable or declined slightly since the late 1980s. Based on data from 1994 through 1996, these rates are 5.39×10^{-8}, 8.64×10^{-8}, and 1.05×10^{-8} per railcar-kilometer, respectively (DIRS 103455-Saricks and Tompkins 1999, Table 6). This conclusion is based on applying denominators that do *not* include train and car kilometers for intermodal shipments (containers and trailers-on-flatcar) not loaded by the carriers themselves. Thus, the actual denominators are probably higher and the rates consequently lower, by about 20 percent.

During the 24 years of the Proposed Action, the *mostly rail* national transportation scenario would involve as many as 10,000 rail shipments of spent nuclear fuel and high-level radioactive waste. Based on the data in DIRS 103455-Saricks and Tompkins (1999, Table 6), the analysis estimated that these shipments could involve eight accidents. More than 99.99 percent of these accidents would not generate forces capable of causing functional damage to the cask; these accidents would have no radiological consequences. A small fraction of the accidents could generate forces capable of damaging the cask. For the *mostly legal-weight truck* scenario, rail accidents would be unlikely during the 300 railcar shipments of naval spent nuclear fuel.

Rates for Barge Accidents

Waterway results show a general improvement over mid-1980s rates. The respective rates for 450-metric-ton (500-ton) shipments for waters internal to the coast (rivers, lakes, canals, etc.) for accident and incident involvements and fatalities were 1.68×10^{-6} and 8.76×10^{-9} per shipment-kilometer, respectively (DIRS 103455-Saricks and Tompkins 1999, Table 8b). Rates for lake shipping were lower—2.58×10^{-7} and 0 per shipment-kilometer, for accidents and incidents and for fatalities, respectively. Coastal casualty involvement rates have risen in comparison to the data recorded about 10 years ago, and are comparable to rates for internal waters—5.29×10^{-7} and 8.76×10^{-9} per shipment-kilometer (DIRS 103455-Saricks and Tompkins 1999, Table 9b).

During the 24 years of the Proposed Action, the *mostly rail* national transportation scenario could involve the use of barges to ship spent nuclear fuel from 17 commercial sites. Based on the data in DIRS 103455-Saricks and Tompkins (1999, all), the analysis estimated that less than one accident could occur during such shipments. A barge accident severe enough to cause measurable damage to a shipping cask would be highly unlikely.

Rates for Safe Secure Trailer Accidents

DOE uses safe secure trailers to transport hazardous cargoes in the continental United States. The criteria used for reporting accidents involving these trailers are damage in excess of $500, a fire, a fatality, or damage sufficient for the trailer to be towed. From 1975 through 1998, 14 accidents involved safe secure trailers over about 54 million kilometers (about 34 million miles) of travel, which yields a rate of 2.6×10^{-7} accident per kilometer (4.2×10^{-7} per mile). This rate is comparable to the rate estimated by DIRS 103455-Saricks and Tompkins (1999, Table 4) for heavy combination trucks, 3.2×10^{-7} accident per kilometer (5.1×10^{-7} per mile).

J.1.4.2.3.3 Accident Data Provided by the States of Nevada, California, South Carolina, Illinois, and Nebraska. In May 1998, DOE requested the 48 contiguous states to provide truck and rail transportation accident data for use in this EIS. Five states responded – Nevada, California, Illinois, Nebraska, and South Carolina (DIRS 104728-Denison 1998, all; DIRS 103709-Caltrans 1997, all; DIRS 104801-Wort 1998, all; DIRS 104783-Kohles 1998, all; DIRS 103725-SCDPS 1997, all). No states provided rail information.

- *Nevada.* Nevada provided a highway accident rate of 1.1×10^{-6} accident per kilometer (1.8×10^{-6} per mile) for interstate carriers over all road types. This is higher than the accident rate estimated by DIRS 103455-Saricks and Tompkins (1999, Table 4); 2.5×10^{-7} accident per kilometer (3.9×10^{-7} per mile) for heavy trucks over all road types in Nevada from 1994 to 1996.

  The definition of *accident* used in DIRS 103455-Saricks and Tompkins (1999, p. 4) is the Federal definition (fatality, injury, or tow-away); in Nevada the accident criteria are fatality, injury, or $750 property damage. Based on national data from the U.S. Department of Transportation Office of Motor Carrier Information Analysis (DIRS 103721-FHWA 1997, p. 2; DIRS 102231-FHWA 1998, pp. 1 and 2), using the Federal definition would reduce the accident rate from 1.1×10^{-6} to about 4.1×10^{-7} accident per kilometer (1.8×10^{-6} to 6.7×10^{-7} per mile). The radiological accident risk in Nevada for the mostly legal-weight truck scenario would increase over 24 years from 0.0002 latent cancer fatality to about 0.0005 latent cancer fatality (a likelihood of 5 in 10,000 of one latent cancer fatality) if the accident rate reported by DIRS 103455-Saricks and Tompkins (1999, p. 33) for Nevada were replaced by the rate of 4.1×10^{-7} per kilometer. Thus, the impacts of the rate for accidents involving large trucks on Nevada highways reported by Nevada (DIRS 104728-Denison 1998, all) would be comparable to the impacts derived using the rate estimated by DIRS 103455-Saricks and Tompkins (1999, p. 33).

- *California.* California responded with highway accident rates that included all vehicles (cars, buses, and trucks). The accident rate for Interstate highways was 4.2×10^{-7} accident per kilometer (6.8×10^{-7} per mile) for all vehicles in 1996. This rate is higher than the accident rate estimated by DIRS 103455-Saricks and Tompkins (1999, Table 4), 1.6×10^{-7} accident per kilometer (2.6×10^{-7} per mile) for heavy trucks on California interstate highways from 1994 to 1996.

  The definition of *accident* in DIRS 103455-Saricks and Tompkins (1999, p. 4) is the Federal definition (fatality, injury, or tow-away); in California the accident criteria are fatality, injury, or $500 property damage. Based on national data from DIRS 103721-FHWA (1997, p. 2) and DIRS 102231-FHWA (1998, pp. 1 and 2), using the Federal definition would reduce the accident rate from 4.2×10^{-7} to about 1.6×10^{-7} accident per kilometer (6.8×10^{-7} to 2.6×10^{-7} per mile). In addition, the rate provided by California was for all vehicles. Based on national data from the U.S. Department of Transportation Bureau of Transportation Statistics, using the accident rate for large trucks would reduce the all-vehicle accident rate from 1.6×10^{-7} to about 1.3×10^{-7} accident per kilometer (2.6×10^{-7} to 2.1×10^{-7} per mile) for large trucks. This rate is slightly less than the rate estimated by DIRS 103455-Saricks and Tompkins (1999, Table 4), 1.6×10^{-7} accident per kilometer.

- *Illinois.* Illinois provided highway data for semi-trucks from 1991 through 1995 over all road types. Over this period, the accident rate was 1.8×10^{-6} accident per kilometer (2.9×10^{-6} per mile). From 1994 through 1996, DIRS 103455-Saricks and Tompkins (1999, all) estimated an accident rate of 3.0×10^{-7} accident per kilometer (4.8×10^{-7} per mile) for heavy trucks over all road types in Illinois.

  The definition of *accident* used in DIRS 103455-Saricks and Tompkins (1999, p. 4) is the Federal definition (fatality, injury, or tow-away); in Illinois the accident criteria are fatality, injury, or $500 property damage. Based on national data from the U.S. Department of Transportation Office of Motor Carrier Information Analysis (DIRS 103721-FHWA 1997, p. 2; DIRS 102231-FHWA 1998, pp. 1 and 2), using the Federal definition would reduce the accident rate from 1.8×10^{-6} to about 6.7×10^{-7} accident per kilometer (2.9×10^{-6} to 1.1×10^{-6} per mile). This rate is comparable to the rate estimated by DIRS 103455-Saricks and Tompkins (1999, all).

- *Nebraska.* Nebraska provided a highway accident rate of 2.4×10^{-7} accident per kilometer (3.8×10^{-7} per mile) for 1997. Nebraska did not specify if the rate was for interstate highways, but it is for interstate truck carriers. This rate is slightly less than the accident rate estimated by DIRS 103455-Saricks and Tompkins (1999, all) for Nebraska interstates, 3.2×10^{-7} accident per kilometer (5.1×10^{-7} per mile) for heavy trucks from 1994 through 1996.

- *South Carolina.* South Carolina responded with highway accident rates that included all types of tractor/trailers (for example, mobile homes, semi-trailers, utility trailers, farm trailers, trailers with boats, camper trailers, towed motor homes, petroleum tankers, lowboy trailers, auto carrier trailers, flatbed trailers, and twin trailers). The rate was 8.3×10^{-7} accident per kilometer (1.3×10^{-6} per mile), for all road types. [This is higher than the accident rate estimated by DIRS 103455-Saricks and Tompkins (1999, all), 4.7×10^{-7} accident per kilometer (7.6×10^{-7} per mile) for heavy trucks on all road types in South Carolina from 1994 through 1996].

  The definition of *accident* in DIRS 103455-Saricks and Tompkins (1999, p. 4) is the Federal definition (fatality, injury, or tow-away); in South Carolina the accident criteria are fatality, injury, or $1,000 property damage. Based on national data from the U.S. Department of Transportation Office of Motor Carrier Information Analysis (DIRS 103721-FHWA 1997, p. 2; DIRS 102231-FHWA 1998, pp. 1 and 2), using the Federal definition of an accident would reduce the accident rate from 8.3×10^{-7} to about 3.1×10^{-7} accident per kilometer (1.3×10^{-6} to 5.0×10^{-7} per mile), which is slightly less than the rate estimated by DIRS 103455-Saricks and Tompkins (1999, all), 4.7×10^{-7} accident per kilometer (7.6×10^{-7} per mile). In addition, the accident rate estimated by DIRS 103455-Saricks and Tompkins (1999, all) was based on Motor Carrier Management Information System vehicle configuration codes 4 through 8 (truck/trailer, bobtail, tractor/semi-trailer, tractor/double, and tractor/triple), while the rate obtained from South Carolina included all truck/trailer combinations. Including all of the combinations tends to increase accident rates; for example, light trucks have higher accident rates than heavy trucks (DIRS 148081-BTS 1999, Table 3-22).

DOE evaluated the effect of using the data provided by the five states on radiological accident risk for the mostly legal-weight truck national transportation scenario. If the data used in the analysis for the five states (DIRS 103455-Saricks and Tompkins 1999, Table 4) were replaced by the data provided by the states with the adjustments discussed, the change in the resulting estimate of radiological accident risk would be small, increasing from 0.067 to 0.071 latent cancer fatality. Using the unadjusted data provided by those states would result in an increase in accident risk from 0.067 to 0.093 latent cancer fatality.

J.1.4.2.4 *Transportation Accidents Involving Nonradioactive Hazardous Materials*

The analysis of impacts of transportation accidents involving the transport of nonradioactive hazardous materials to and from Yucca Mountain used information presented in two U.S. Department of Transportation reports (DIRS 103718-DOT 1998, Table 1; DIRS 103708-BTS 1996, p. 43) on the annual number of hazardous materials shipments in the United States and the number of deaths caused by hazardous cargoes in 1995. In total, there are about 300 million annual shipments of hazardous materials; only a small fraction involve radioactive materials. In 1995, 6 fatalities occurred because of hazardous cargoes. These data suggest a rate of 2 fatalities per 100 million shipments of hazardous materials. DOE anticipates about 40,000 shipments of nonradioactive hazardous materials (including diesel fuel and laboratory and industrial chemicals) to and from the Yucca Mountain site during construction, operation and monitoring, and closure of the repository. Assuming that the rate for fatalities applies to the transportation of nonradioactive hazardous materials to and from Yucca Mountain, DOE does not expect fatalities from 40,000 shipments of these materials.

J.1.4.2.5 *Cost of Cleanup and Ecological Restoration Following a Transportation Accident*

Cost of Cleanup. According to the Nuclear Regulatory Commission report *Reexamination of Spent Fuel Shipment Risk Estimates* (DIRS 152476-Sprung et al. 2000, pp. 7-73 to 7-76), in more than 99.99 percent of accidents radioactive material would not be released from the cask. After initial safety precautions had been taken, the cask would be recovered and removed from the accident scene. Because no radioactive material would be released, based on reported experience with two previous accidents (DIRS 156110-FEMA 2000, Appendix G, Case 4 and Case 5), the economic costs of these accidents would be minimal.

For the 0.01 percent of accidents severe enough to cause a release of radioactive material from a cask, a number of interrelated factors would affect costs of cleaning up resulting radioactive contamination after the accident. Included are: the severity of the accident and the initial level of contamination; the weather at the time and following; the location and size of the affected land area and how the land is used; the standard established for the allowable level of residual contamination following cleanup and the decontamination method used; and the technical requirements for and location for disposal of contaminated materials.

Because it would be necessary to specify each of the factors to estimate clean up costs, any estimate for a single accident would be highly uncertain and speculative. Nonetheless, to provide a gauge of the costs that could be incurred DOE examined past studies of costs of cleanup following hypothetical accidents that would involve uncontrolled releases of radioactive materials.

A study of the impacts of transporting radioactive materials conducted by the Nuclear Regulatory Commission in 1977 estimated that costs could range from about $1 million to $100 million for a transportation accident that involved a 600-curie release of a long-lived radionuclide (DIRS 101892-NRC 1977, Table 5-11). These estimates would be about 3 times higher if escalated for inflation from 1977 to the present. In 1980 DIRS 155054-Finley et al. (1980, Table 6-9) estimated that costs could range from about $90 million to $2 billion for a severe spent nuclear fuel transportation accident in an urban area. DIRS 154814-Sandquist et al. (1985, Table 3-7) estimated that costs could range from about $200,000 to $620 million. In this study, Sandquist estimated that contamination would affect between 0.063 to 4.3 square kilometers (16 to 1,100 acres). A study by DIRS 152083-Chanin and Murfin (1996, Chapter 6) estimated the costs of cleanup following a transportation accident in which plutonium would be dispersed. This study developed cost estimates for cleaning up and remediating farmland, urban areas, rangeland, and forests. The estimates ranged from $38 million to $400 million per square kilometer that would need to be cleaned up. The study also evaluated the costs of expedited cleanups in urban areas for light, moderate, and heavy contamination levels. These estimates ranged from $89 million to $400 million per square kilometer.

The National Aeronautics and Space Administration studied potential accidents for the Cassini mission, which used a plutonium powered electricity generator. The Agency estimated that costs of cleaning up radioactive material contamination on land following potential launch and reentry accidents. The estimate for the cost following a launch accident ranged from $7 million to $70 million (DIRS 155551-NASA 1995, Chapter 4) with an estimated contaminated land area of about 1.4 square kilometers (350 acres). The Agency assumed cleanup costs would be $5 million per square kilometer if removal and disposal of contaminated soil were not required and $50 million per square kilometer if those activities were required. For a reentry accident that would occur over land, the study estimated that the contaminated land area could range from about 1,500 to 5,700 square kilometers (370,000 to 1.4 million acres) (DIRS 155551-NASA 1995, Chapter 4) with cleanup costs possibly exceeding a total of $10 billion. In a more recent study of potential consequences of accidents that could involve the Cassini mission, NASA estimated that costs could range from $7.5 million to $1 billion (DIRS 155550-NASA 1997, Chapter 4). The contaminated land area associated with these costs ranged from 1.5 to 20 square kilometers (370 to 4,900 acres). As in the 1995 study, these estimates were based on cleanup costs in the range of $5 million to $50 million per square kilometer.

Using only the estimates provided by these studies, the costs of cleanup following a severe transportation accident involving spent nuclear fuel where radioactive material was released could be in the range from $300,000 (after adjusting for inflation from 1985 to the present) to $10 billion. Among the reasons for this wide range are different assumptions made regarding the factors that must be considered: 1) the severity of the assumed accident and resulting contamination levels, 2) accident location and use of affected land areas, 3) meteorological conditions, 4) cleanup levels and decontamination methods, and 5) disposal of contaminated materials. However, the extreme high estimates of costs are based on assumptions that all factors combine in the most disadvantageous way to create a "worst case." Such worst cases are not reasonably foreseeable. Conversely, estimates as low as $300,000 may also not be realistic for all of the direct and indirect costs of cleaning up following an accident severe enough to cause a release of radioactive materials.

To gauge the range of costs that it could expect for severe accidents in transporting spent nuclear fuel to a Yucca Mountain repository, DOE considered the spectrum of accidents that are reasonably foreseeable (see Section J.1.4.2.1) and the amount of radioactive material that could be released in each such accident and compared this to the estimates of releases used by the various studies discussed above. Based on 2 million curies of radioactive material in a rail casks loaded with spent nuclear fuel, about 13 curies (mostly cesium) would be released in a maximum reasonably foreseeable accident. This is about 100 times less than used by Sandquist in his study (1,630 curies) and 50 times less than the release used in the estimates provided by the Nuclear Regulatory Commission in 1977 (600 curies). The estimated frequency for an accident this severe to occur is about 3 times in 10 million years. Based on the prior studies (where estimated releases exceeded those estimated in this appendix for a maximum reasonably foreseeable accident) and the amount of radioactive material that could be released in a maximum reasonably foreseeable accident, the Department believes that the cost of cleaning up following such an accident could be a few million dollars. Nonetheless, as stated above, the Department also believes that estimates of such costs contain great uncertainty and are speculative; they could be less or 10 times greater depending on the contributing factors.

For perspective, the current insured limit of responsibility for an accident involving releases of radioactive materials to the environment is $9.43 billion (see Appendix M). The annual cost of transporting spent nuclear fuel and high-level radioactive waste to Yucca Mountain would be about $200 million.

Ecological Restoration. Following a severe transportation accident, it might be necessary to restore the ecology of an area after the area was remediated. DIRS 152083-Chanin and Murfin (1996, all) present a review of the scope of ecological restoration that can be accomplished and the requirements that would apply in the event of an accident where environmental damage resulting from cleaning up radioactive material contamination would in turn result in a need for environmental restoration. The restoration that would be necessary following an accident cannot be predicted. It would depend on the environmental factors involved—1) the levels of contamination from the accident, 2) cleanup levels and decontamination methods used, and 3) location and ecology of the affected land areas—and the restoration goal that was used. DIRS 152083-Chanin and Murfin (1996, Chapter 6) observe

> *"[a] long-standing definition of the preferred goal of site restoration is to establish an ecological community as similar as possible to that which existed before an accident. Alternative goals are to*

establish a similar, but not identical, community; to establish an entirely different but valued community; or, if none of the foregoing is feasible, to establish some less-valued community."

The costs discussed above include costs for environmental restoration.

DIRS 152083-Chanin and Murfin (1996, all) provide the following assessments of environmental restoration that could be accomplished following clean up of contamination from an accident.

- Unassisted restoration of desert land is difficult, but assisted restoration can be very successful.
- Grasslands may be restored naturally provided only limited soil has been removed. Assisted restoration of prairies is also successful.
- Total restoration of forests may not be possible if the area is too large for natural reseeding; an alternative use may have to be found for forestland.
- Restoration of farmland is relatively simple.
- Restoration of urban land to building sites is simple.
- Restoration to parkland is possible, but more costly.

J.2 Evaluation of Rail and Intermodal Transportation

DOE could use several modes of transportation to ship spent nuclear fuel from the 72 commercial and 5 DOE sites. Legal-weight trucks could transport spent nuclear fuel and high-level radioactive waste in truck casks that would weigh approximately 22,500 kilograms (25 tons) when loaded. For sites served by railroads, railcars could be used to ship rail casks directly to the Yucca Mountain site, if a branch rail line was built in Nevada, or to an intermodal transfer station in Nevada if heavy-haul trucks were used. Rail casks would weigh as much as 136,000 kilograms (150 tons).

For sites that have the capability to load rail casks but are not served by a railroad, DOE could use heavy-haul trucks or, for sites on navigable waterways, barges to transport casks to nearby railheads.

For rail shipments, DOE could request the railroads to provide dedicated trains to transport casks from the sites to a destination in Nevada or could deliver railcars with loaded casks to the railroads as general freight for delivery in Nevada.

In addition, DOE evaluated the potential for including two other scenarios: (1) a different mostly rail scenario in which railcars would transport legal-weight truck casks and (2) a large-scale barge scenario.

J.2.1 LEGAL-WEIGHT TRUCK CASKS ON RAILCARS SCENARIO

DOE assessed the sensitivity of transportation impacts to assumptions related to transportation scenarios. The analysis evaluated a variation of the mostly rail scenario in which shipments would be made using casks much smaller than rail casks—legal-weight truck casks—shipped to Nevada on railcars then transported on legal-weight trucks from a rail siding to Yucca Mountain. Under this scenario, because all shipments (except shipments of naval spent nuclear fuel) would use legal-weight truck casks, the number of railcar shipments would be about 53,000 over the 24 years of the Proposed Action. This would be the same as the number of legal-weight truck plus naval spent nuclear fuel shipments in the mostly legal-weight truck scenario.